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HIGHWAY RESEARCH REPORT

CALIBRATION AND BEDDING MATERIAL STUDY FOR EARTH PRESSURE CELLS

INTERIM REPORT

STATE OF CALIFORNIA

BUSINESS AND TRANSPORTATION AGENCY

DEPARTMENT OF PUBLIC WORKS

DIVISION OF HIGHWAYS

MATERIALS AND RESEARCH DEPARTMENT

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STATE OF CALIFORNIA—BUSINESS AND TRANSPORTATION AGENCY

RONALD REAGAN, Governor

DEPARTMENT OF PUBLIC WORKS
DIVISION OF HIGHWAYS
MATERIALS AND RESEARCH DEPARTMENT
5900 FOLSOM BLVD., SACRAMENTO 95819

Interim Report
M & R No. 632954-2
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April 1972

Mr. R. J. Datel
State Highway Engineer

Dear Sir:

Submitted herewith is a research report titled:

CALIBRATION AND BEDDING MATERIAL STUDY

FOR

EARTH PRESSURE CELLS

Travis Smith

Principal Investigator

Raymond Forsyth

Co-Investigator

Analysis and Report

John Boss   Kenneth Jackura

Very truly yours,

JOHN L. BEATON
Materials and Research Engineer

REFERENCE

Smith, Travis, Forsyth, Raymond, Boss, John, and Jackura, Kenneth, "Calibration and Bedding Material Study for Earth Pressure Cells," State of California, Department of Public Works, Division of Highways, Materials and Research Department, Interim Research Report CA-HWY-MR632954(2)-72-03 April, 1972.

ABSTRACT

Two basic methods of calibrating earth pressure cells are evaluated: (a) compressing earth pressure cells between pads of various soft backing materials utilizing a rigid frame, hydraulic jack and load cell arrangement, and (b) hydrostatic pressurization. The main purpose of this evaluation was to determine which method would result in a more consistent or reproducible calibration curve.

Also investigated was the effect of various types of bedding materials on pressure cell performance. This was accomplished by embedding pressure cells in cohesive or cohesionless soils contained in a laboratory-built pressure vessel, applying a hydrostatic pressure to the soil surface, and then comparing cell responses to the hydrostatic calibration curve. Pressure cell responses were analyzed to determine the more desirable bedding material. Factors considered were reproducibility, cell response to actual applied pressure, pressure vessel parameters, and depth of cover.

KEY WORDS: Soil pressure, pressure cells, calibrations, bedding materials, measurements, methods.

ACKNOWLEDGMENTS

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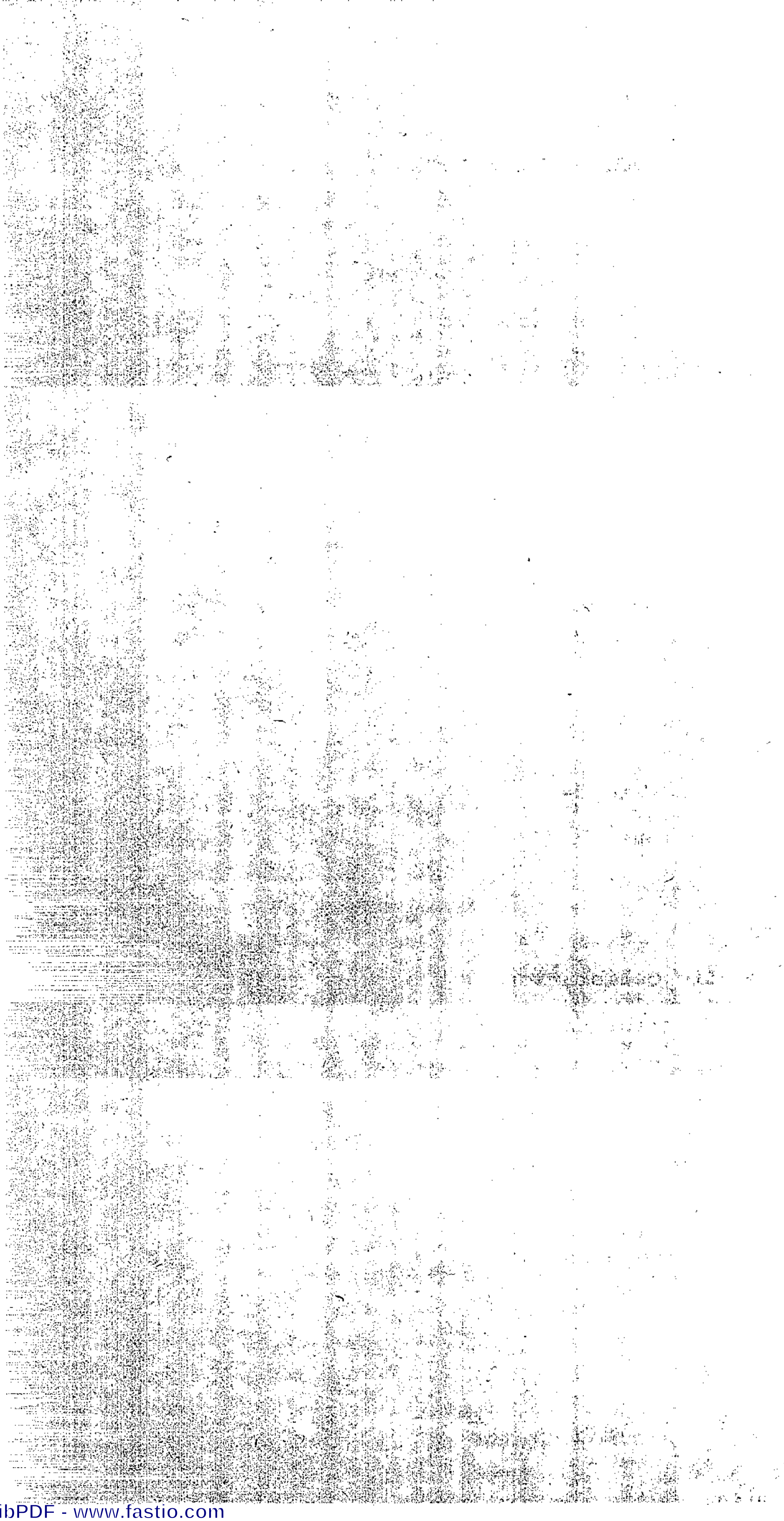

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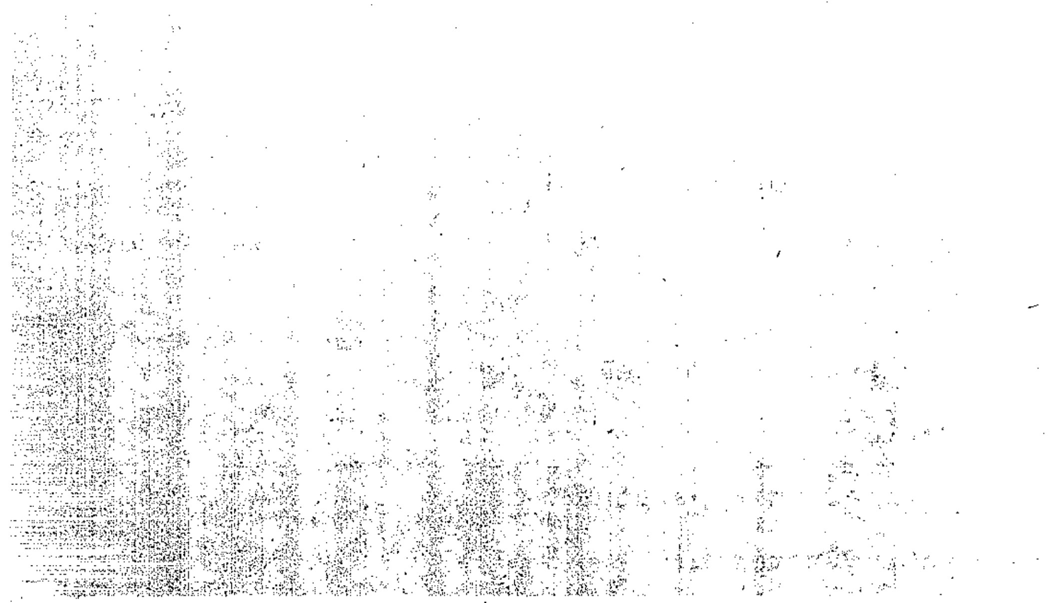

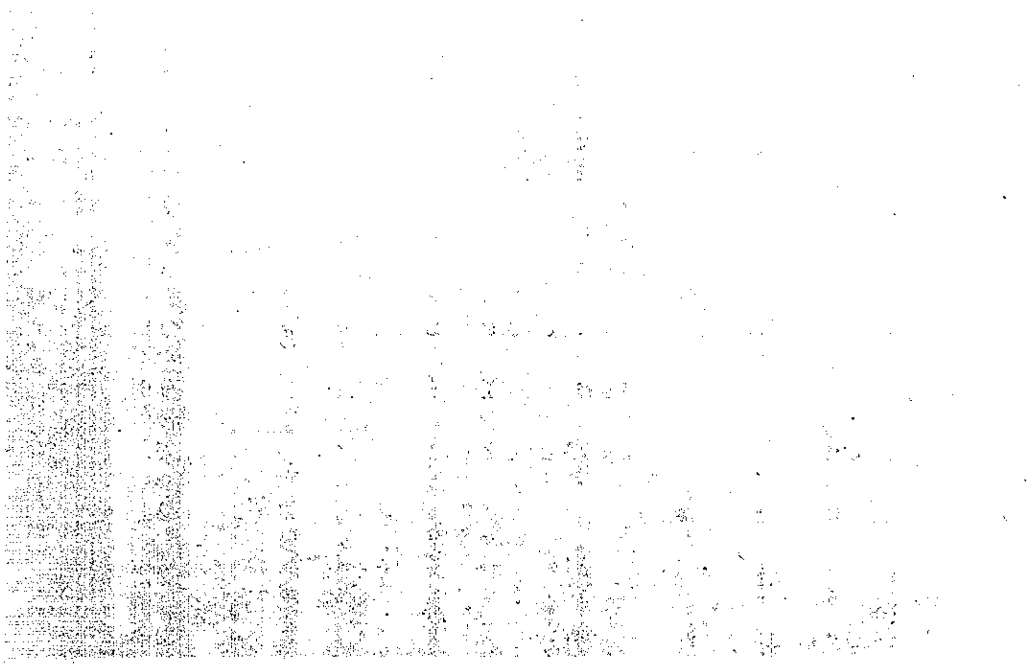

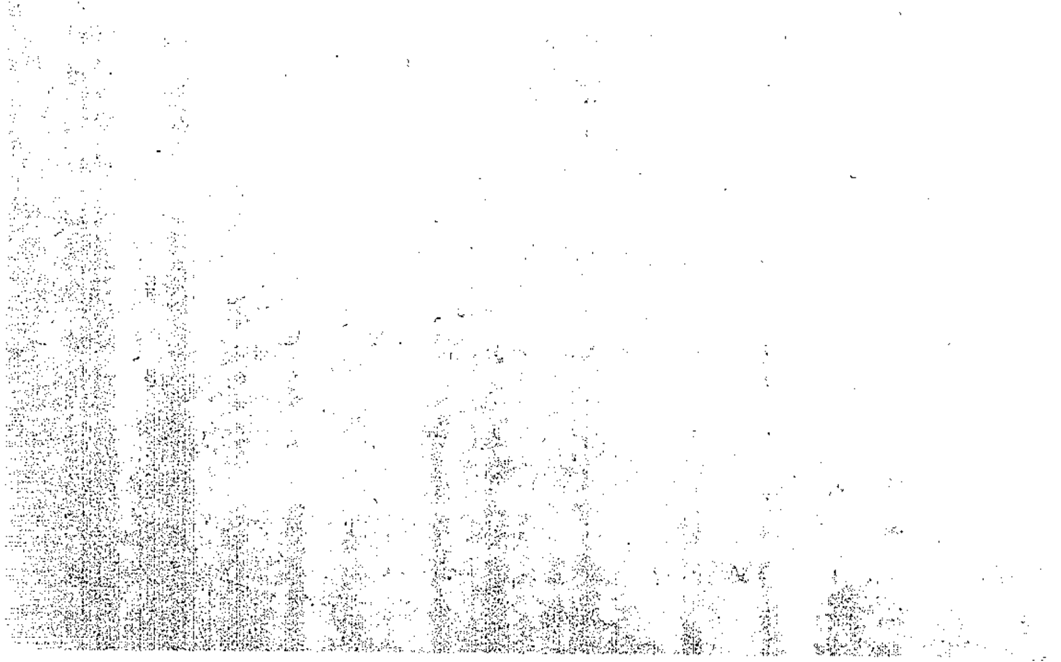

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INTRODUCTION

The California Division of Highways in recent years has designed and constructed numerous high embankments (up to 400 feet in height). To gain a better understanding of the behavior of these fills and culverts underneath them, a number of these were instrumented and monitored. A variety of soil pressure cells were employed to monitor soil stress within these fills.

In several instances the monitored soil stresses varied widely from those predicted by overburden stress calculations. The possibility of these being valid readings was not discounted. However, several other possible factors contributing to these apparent discrepancies were considered. These included (1) faulty cell design criteria, (2) mechanical failure of the cell or readout unit, (3) non-compactibility of soil and cell elastic moduli, (4) wide variations of "cell bedding material" elastic moduli, and (5) poor correlation of cell calibration methods with field conditions.

Pressure cell design criteria have been given careful consideration by various investigators, and such criteria were incorporated into the pressure cells used for this study (References 1, 2, 3, 4 and 5). Also, the mechanical features of these cells have been studied extensively through quality control testing within the laboratory and field evaluation (References 6 and 7). In addition, the inclusion effect of rigid to semi-rigid pressure cells within a soil mass is well documented (References 1, 2, 3 and 4). However, information relating the effect of bedding materials on pressure cell response was found to be inconclusive, and calibration techniques that would accurately reflect field stress conditions were lacking. It was these two factors that were heavily emphasized in this phase of the research project.

The original method of the Division of Highways for calibrating earth pressure cells was fairly simple and inexpensive. The technique is basically a load/area method in which the cell is compressed between hardwood pads utilizing a hydraulic jack, load cell, and reaction frame combination. The applied load was assumed to be distributed uniformly over the cell surfaces and the hardwood pads assumed to contact the cell in a manner similar to soil. However, the resulting data plots tended to be nonlinear, and reproducibility was questionable. This problem indicated the need for a more positive and reproducible method of calibration and clearer understanding of the effects of various bedding materials on the response of soil pressure cells. Accordingly, a laboratory test chamber was devised to permit placement of cells within a soil mass with a known soil surface stress condition, leading to subsequent evaluations of the pressure cell response.

CONCLUSIONS

1. The results of this investigation indicate the superiority of the hydrostatic method of calibrating earth pressure cells. The previously accepted Division of Highways method of calibration utilizing a hydraulic jack, reaction frame, and various types of backing materials did not produce as consistent or as linear a calibration curve as the hydrostatic method.

2. Cohesive soils should not be considered for use as a bedding material unless as a continuum of the embankment. Response characteristics, especially where lateral stresses were measured, varied with moisture content and were nonlinear on the loading cycle. Also, overregistration varied depending on the initial water content.

3. Cell response characteristics were similar for bedding materials composed of either medium coarse sand or fine pea gravel. Cell overregistration was approximately 6 percent for sand whereas cells underregistered about 2 percent for the pea gravel. However, both materials exhibited linear vertical and lateral cell stress responses up to the maximum tested pressure of 200 psi.

4. Side wall friction was investigated and found to introduce a significant variation in test results. The use of a greased liner, however, significantly reduced side friction and increased cell responses approximately 5 percent when compared with similar tests conducted in an unlubricated mold (based on tests conducted in sand).

5. Cell response proved to be a function of embedment depth. For the two cell depths investigated (4 in. and 8 in.), the 8 in. embedment depth resulted in lower cell responses than those for cells embedded at 4 in. This was true for both the lubricated and unlubricated molds. This variation in cell response with location and depth is due, in part, to the arching action in the soil caused by the geometry of the test chamber.

DISCUSSION

A. Literature Review

Although not covered by this report, cell design is of fundamental importance in the measurement of field stress conditions. The inclusion of a foreign body into a soil mass whose stress-deformation characteristics are radically different from that of the cell can result in inaccurate stress readings at the point of installation. Taylor (1) in 1945 considered the different compressibilities of soil and cell and presented theoretical relationships for determining cell error due to this factor. He proposed using suitable correction factors to account for the inclusion effect involving modulus of elasticity of soil and cell. This study, however, represents an effort to develop this correction experimentally. Therefore, emperical methods based on laboratory testing were utilized. Since full scale field testing incurs large expenses, a laboratory method utilizing a pressure vessel to induce stresses of known magnitudes appeared to be a simpler and less costly solution.

Several other investigators have utilized such test methods with various degrees of success. Taylor (1) in his study for the U.S. Waterways Experiment Station evaluated test results which enlisted the use of a pressure vessel. Results were quite encouraging even though side frictional effects were readily apparent. He recommended that to reduce effect of frictional resistance and develop a full pressure bulb region, future studies consist of tests where mold-cell diameter and depth ratios be on the order of 8:1 and 4:1, respectively.

Peattie and Sparrow (2) in their investigation of pressure cell action also used a pressure vessel. It was initially assumed, and then demonstrated, that the pressure at the plane of the cell is directly proportional to the free field pressure applied at the soil surface. Since a series of cells were placed at the same depth, this approach worked out quite well in developing curves which isolated the effects of side friction. Trollope and Lee (3) also conducted tests using a pressure vessel. They accounted for side friction by utilizing thin concentric rings at the base of the vessel, measuring the force on each ring, and correlating the base pressures to the measured response of embedded earth pressure cells.

The U.S. Army Experiment Station (4) conducted tests utilizing a circular pressure chamber composed of concentric, freely disposed circular rings to eliminate side friction.

Stresses measured in this cell correlate closely to those of duplicate tests conducted in a mold using rigid side walls, but lubricated with grease. This latter solution appeared to be the simplest and most convenient for our purposes and consequently was adopted.

It was anticipated that the lubrication would reduce the effect of the mold-cell diameter and depth ratios actually used in this study (1/3 those recommended by Taylor). These small ratios were necessary to test 10 in. diameter pressure cells in a pressure chamber of practical size.

Bedding soils commonly used in past investigations were either of a medium coarse sand, generally standard Ottawa sand, or some type of a lean sandy clay. McMahon and Yoder (5) compacted soils similar to these along with pressure cells into a brass sleeve which was placed and pressurized in a triaxial cell. A flexible membrane transmitted applied air pressures to the soil. Calibration characteristics of the cells within the two soil types were then compared to those obtained pneumatically. The clay soil calibration curves compared quite well to those obtained with air, but the results in the sand were quite erratic and correlations were poor. Peattie and Sparrow (2) also used a medium sand and lean clay in their experiment. Their findings showed that cells in dense sand had recorded errors of as much as 45 percent. For the clayey soil, cell errors were on the order of 5 percent to 20 percent, depending on moisture content.

Trollope and Lee (3) also found varying cell response between the two materials. Response measurements of cells embedded in sand was fairly erratic, with each loading cycle producing a different stress-cell response path. However, cell response in clay was quite consistant over a number of consecutive loading cycles. In these tests, cells embedded in sand, on the average, underregistered approximately 7 percent, whereas those in clay overregistered about 3 percent.

B. Object of Test Program

The objective of the research was to determine the behavior of earth pressure cells placed within granular and cohesive soils under such conditions that the stresses at the plane of the cell were known, and to compare the results with various cell calibration methods. The following is a general discussion of the salient features of the test program.

C. Materials and Methods

1. Test Chamber

A primary requirement of this test program was the availability of some means to test pressure cells within a soil mass at a location wherein the stress on the cell was known. For this purpose a large pressure vessel was constructed as shown in Fig. 1, and designed so soil could be compacted into the lower half. A membrane covering the soil surface enabled uniform application of a hydrostatic pressure (plane A-A in Fig. 2). The stress on an earth pressure cell placed within reasonable proximity to this plane (plane B-B on Fig. 2) may be assumed to be equal to the hydrostatic pressure. The relative stress within the compacted soil at various locations, and the effects of chamber side friction were investigated, and are discussed in the section dealing with testing of the granular soil.

Figure 1 - Test Chamber

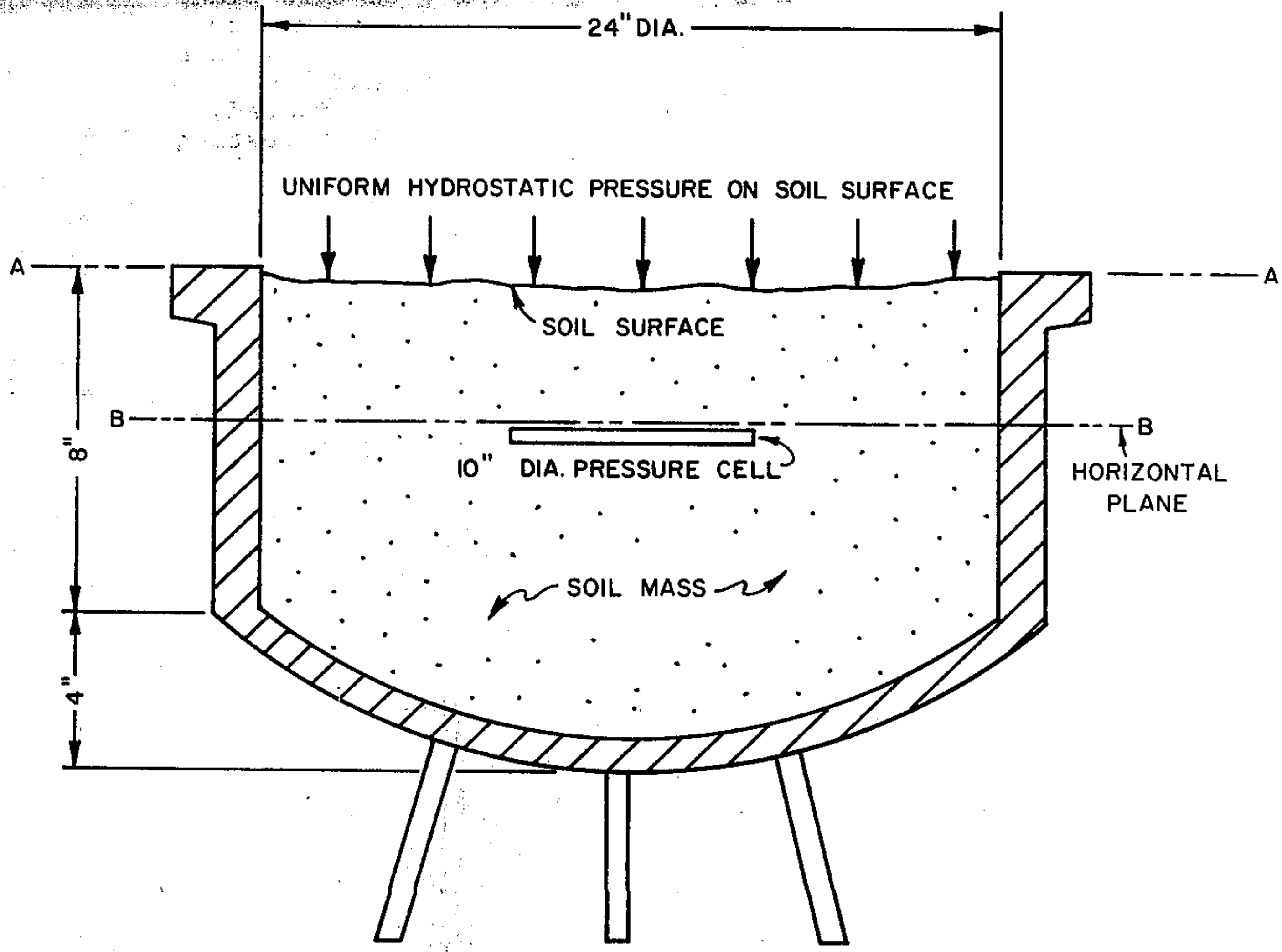


Fig. 2-CROSS SECTION OF PRESSURE VESSEL, SOIL MASS AND EMBEDDED PRESSURE CELL.

The chamber was fabricated from two 1200 psi rated 24 in. diameter hemispherical pipe ends. Flanges were welded to each section and the halves fastened together with eight high-strength steel bolts. Usable void volume for acceptance of the soil (confined to the lower half) is approximately 2 cu. ft.

For safety reasons water was used as a pressurizing medium, which necessitated some type of hydraulic seal at the connection or junction of the two halves. For this the face of one of the flanges was grooved to accept and seat a rubber "O" ring. A variety of fittings located on each hemispherical half permitted application of water, and the entrance and exit of test leads and various hoses and gages.

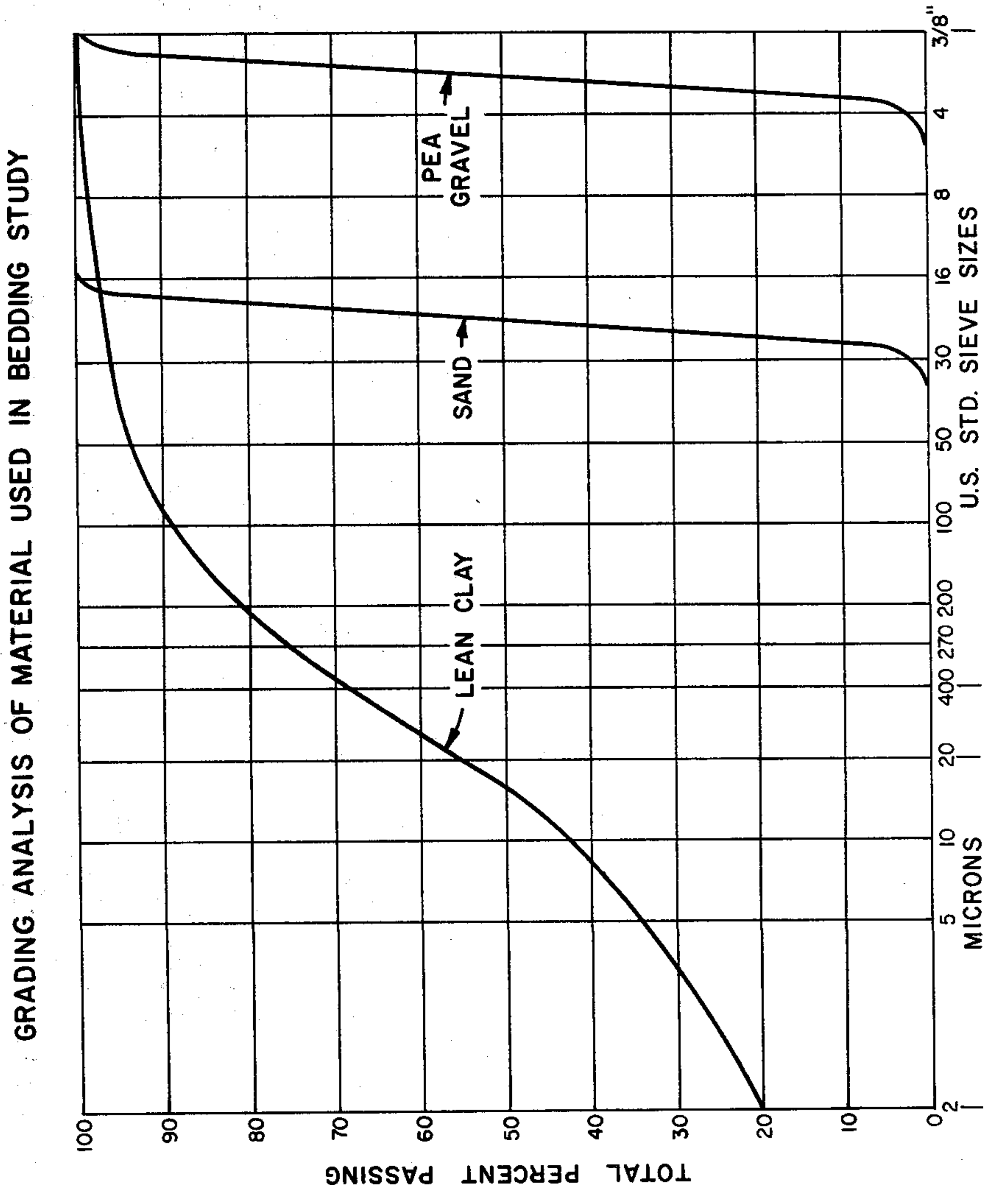
2. Bedding Soils

In the program it was desired to encompass the extremes of the soil types which might ordinarily be employed to bed earth pressure cells. These are conventionally classified as granular and cohesive soils.

a. Granular Soils

It was originally planned to vary the grading of the granular soils in four steps, from that of a sand to pea gravel. It was believed that this selection would indicate the relative change in cell behavior, if any, with increasing degree of coarseness. Thus, the effect of a mixed or uniformly graded granular material could be estimated. The sand and pea gravel sizes were tested initially. It was determined that there was only a slight difference in cell behavior between the two. Consequently, the intervening sizes were not used. The grading characteristics of the sand and pea gravel are shown on Fig. 3. Both materials were obtained from the same stream bed deposit, were gray in color, quite hard, and composed of subrounded to subangular particles. Absorption and apparent specific gravity is approximately 1 percent and 2.65, respectively.

Figure 3


GRADING ANALYSIS OF MATERIAL USED IN BEDDING STUDY
PEA GRAVEL
SAND
LEAN CLAY
U.S. STD. SIEVE SIZES
3/8"
4
8
16
30
50
100
200
270
400
MICRONS
20
10
5
2
TOTAL PERCENT PASSING
100
90
80
70
60
50
40
30
20
10
0

b. Cohesive Soils

For practical reasons associated with handling and compaction, the cohesive soil selected did not represent the extreme of this soil type. The soil used can be described as a "lean clay," (grading characteristics also shown on Fig. 3) with PI and LL of 13 and 33, respectively, and an apparent specific gravity of 2.73.

It was assumed that variations in water content would be the principal factor affecting the performance of an earth pressure cell in cohesive soil. Consequently, the test cells were placed in the cohesive soil at four moisture contents.

3. Calibration Methods

The test program included calibration by two basic methods: hydrostatic calibration of the soil cells within the pressure chamber, and calibration with a load cell in a rigid frame with a hydraulic ram, Fig. 4. In the load cell calibration method, three types of backing material were used, as shown in Fig. 5. These were plywood, preformed fabric-rubber, and neoprene. To estimate stress, the imposed load was divided by the actual gross cell area. These calibration methods are discussed later in greater detail.

4. Cell Selection

The Gentran pressure cells used in the test program were model GT-621 soil pressure cells manufactured by General Transducer Co., Sunnyvale, California. They were arbitrarily selected from a lot of approximately 20 cells on hand which had undergone testing for leakage, long-term load, and diaphragm deflection 1/. Their design load range was 0 to 200 psi.

The Gentran pressure cell is a hydroelectrical device consisting of a hydraulic load sensing unit and an electrical pressure transducer. The load sensing unit consists of two machined steel plate diaphragms welded together so as to form a central cavity (Fig. 6). The cavity contains a light weight machine oil which transmits applied pressure to a pressure transducer diaphragm. A flexure groove milled around the periphery of one of the plates minimizes dishing of the plate diaphragms.

1/ (For a more detailed description, associated compliance tests, and specifications for the GT-621 soil pressure cells, the reader is referred to Highway Research Report No. 632954-1 dated May 1971).

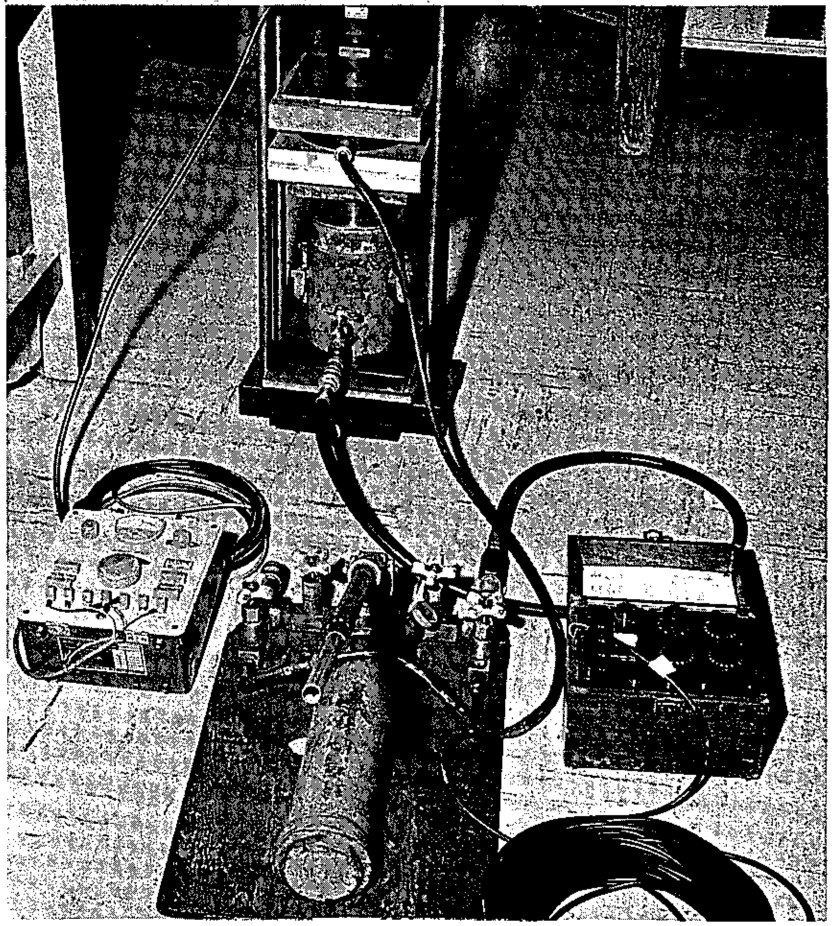


Figure 4 - Rigid Frame Calibration Apparatus

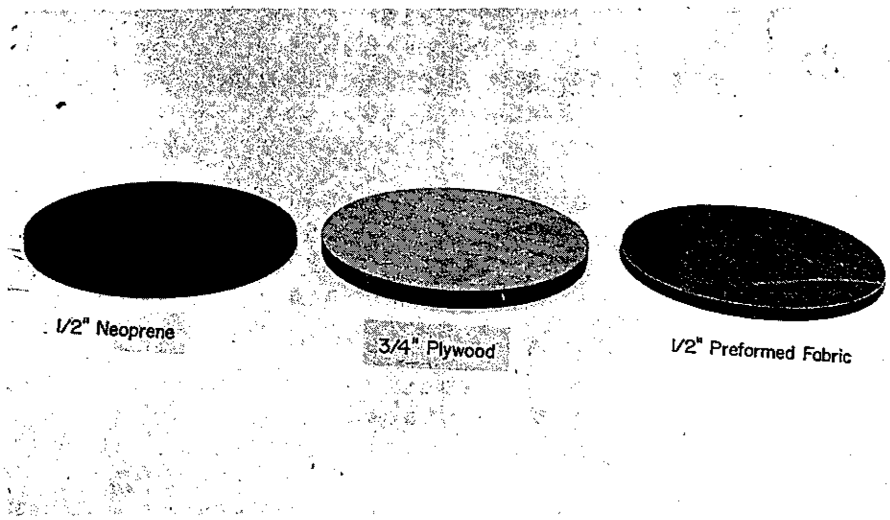


Figure 5 - 3 Types of Pressure Cell Backing Materials
Used in the Rigid Frame Calibration.

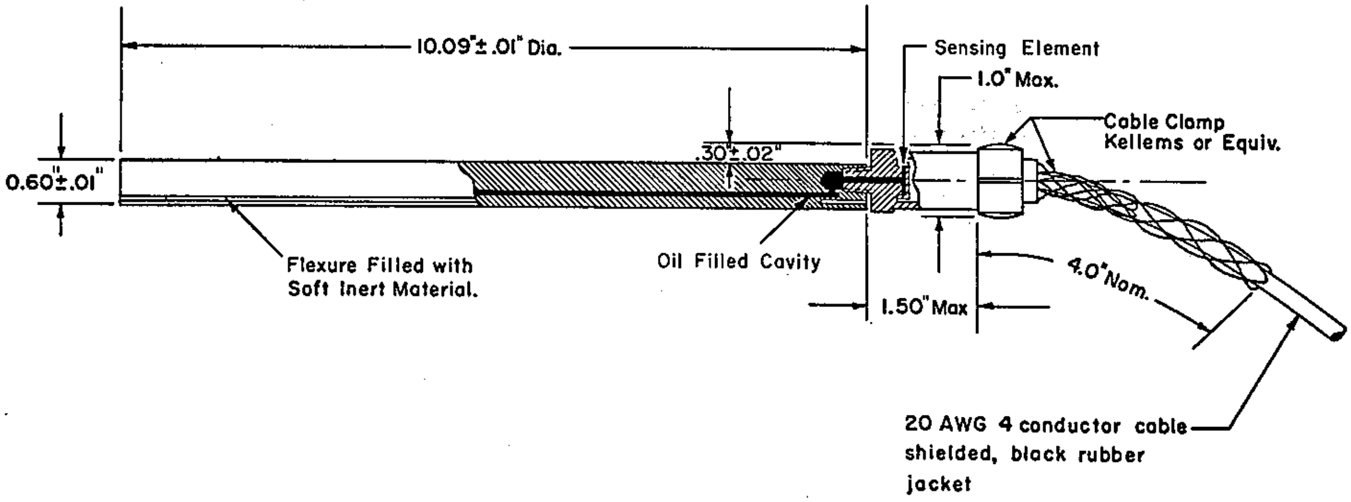


Fig. 6. SOIL STRESS CELL GT-621

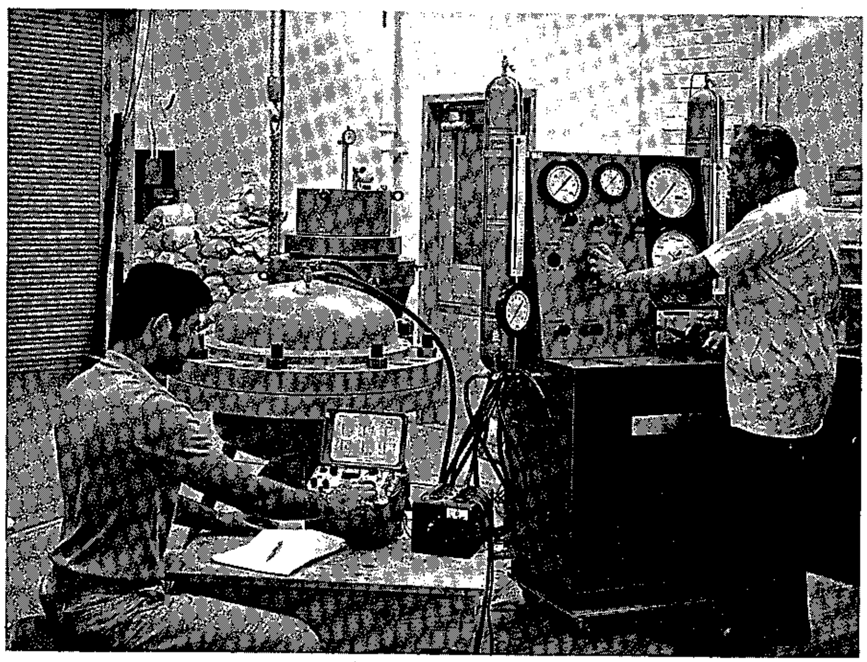


Fig. 7. PRESSURE VESSEL WITH CONTROL CONSOLE.

The pressure transducer is a 350-ohm four-active-arm Wheatstone bridge strain gage assembly mounted on a thin diaphragm. This assembly is housed in a 1-3/4 in. length of 1/2-inch diameter pipe attached to the load sensing unit. Electrical current is transmitted to the transducer by a neoprene jacketed, four-conductor cable. The cable, in turn, is connected to a Strainsert Model HWI-D digital type balancing meter.

5. Cell Arrangement

It was planned that in most tests two of the three pressure cells would be oriented in the horizontal plane to measure the vertical pressure, and one oriented vertically to record the lateral pressure. The lateral stress within the soil mass would not be known, of course, other than as indicated by the cells. However, the relative behavior of the cells within the compacted soils, when subjected to the various loading conditions, could be studied.

D. Calibration

1. Hydrostatic Calibration

The three pressure cells used in the research were calibrated hydrostatically by placing them in the large pressure chamber described earlier and positioned vertically in grooved wooden supports. Pressure cell lead wires extended out the bottom of the chamber and were connected to terminals of a switch box. This arrangement provided a convenient method for changing from one cell to another while recording the strain-gage readings from cell to cell at a given load. The switch box was in turn connected to a Strainsert indicator. Pressure was regulated by a pressure chamber control console through hoses fastened to the top of the chamber, Fig. 7. In order to prevent water entry into the pressure cell transducer, the lead wire at the transducer connection was covered with epoxy. After filling the pressure vessel with water, the calibration technique was as follows:

a. All strain meters and gages were checked and zeroed.

b. The cells were flexed by pressurizing to 200 psi several times, then held at 200 psi for 10 minutes to check for shorting in the event of leaks.

c. The pressure was reduced to zero, and the pressure gages and meters checked for zero reading, then hydrostatic pressures were applied in 20 psi increments up to 200 psi. Cell outputs were recorded at each increment of pressure. The procedure was repeated as the cell was rebounded.

d. The calibration was repeated at least two times. The average index value from the readout instrument was then plotted versus the applied stress.

The individual hydrostatic calibration curves for the three earth pressure cells used are shown on Fig. 8, 9 and 10. An average of the three hydrostatic calibrations is shown on Fig. 11. Also represented on those figures are calibrations obtained by the load/area method. These are discussed in the following section of the report.

Hydrostatic calibration of the pressure cells was performed four times at approximately equal time intervals during this investigation. The calibration curves were linear throughout the 0-200 psi range and extremely reproducible, with the maximum stress variation between the different hydrostatic calibrations less than 2 percent.

2. Load/Area Calibration

Pressure cells were loaded by a manually operated hydraulic jack (20-ton capacity) which was mounted between end plates separated by threaded tension rods (Fig. 4). A 20,000-lb capacity loadcell with a spherical mounted cap to eliminate load eccentricity was used to measure the load applied to the cells. This load cell was calibrated periodically with a 60,000-lb capacity Wiedemann-Baldwin testing machine, with 0.1 percent accuracy. The load cell was connected to a Budd digital readout instrument Model P-350, manufactured by Budd Instrument Co., which was used exclusively for all calibration and testing (Fig. 12).

For calibration, each cell was sandwiched between backing material or pads consisting of either plywood, preformed fabric, or neoprene. The plywood is

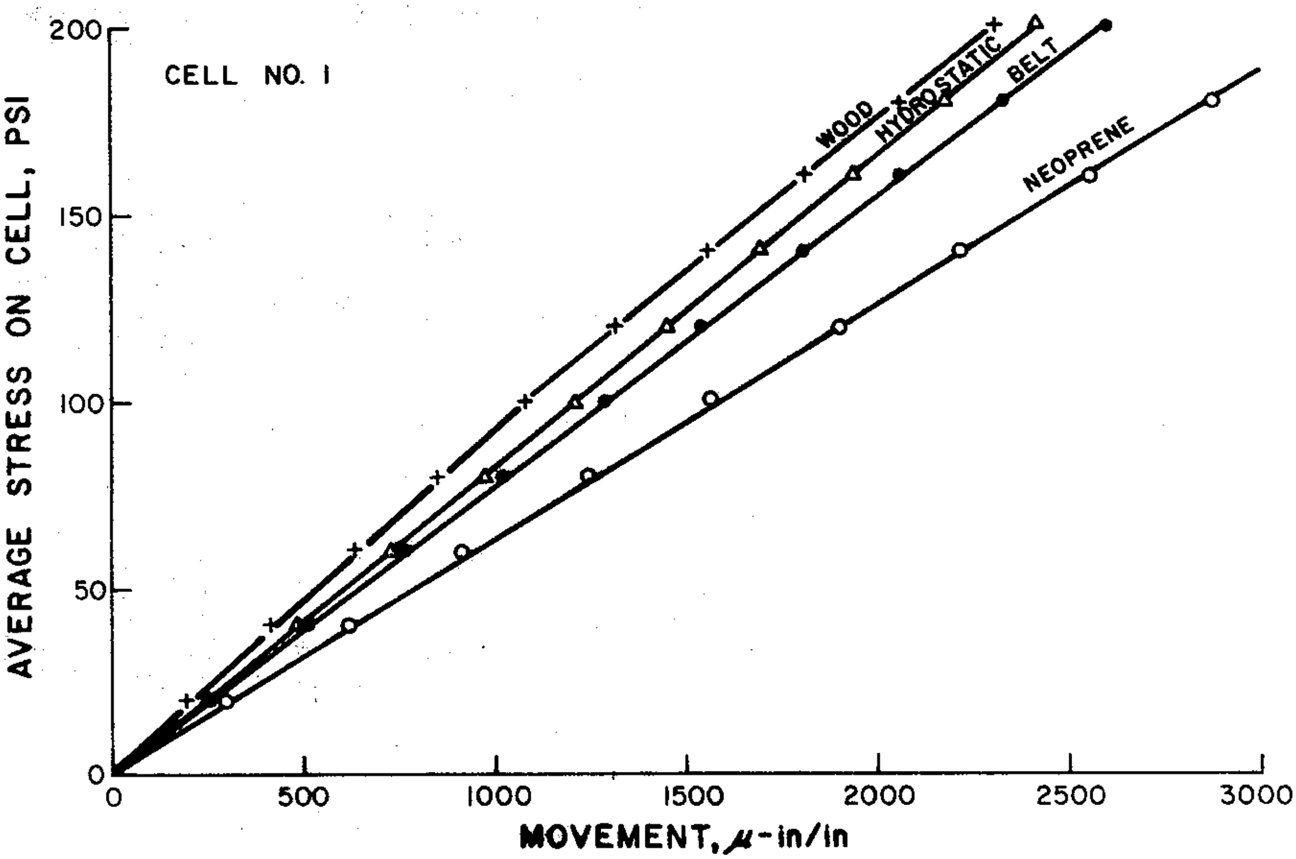


Fig. 8

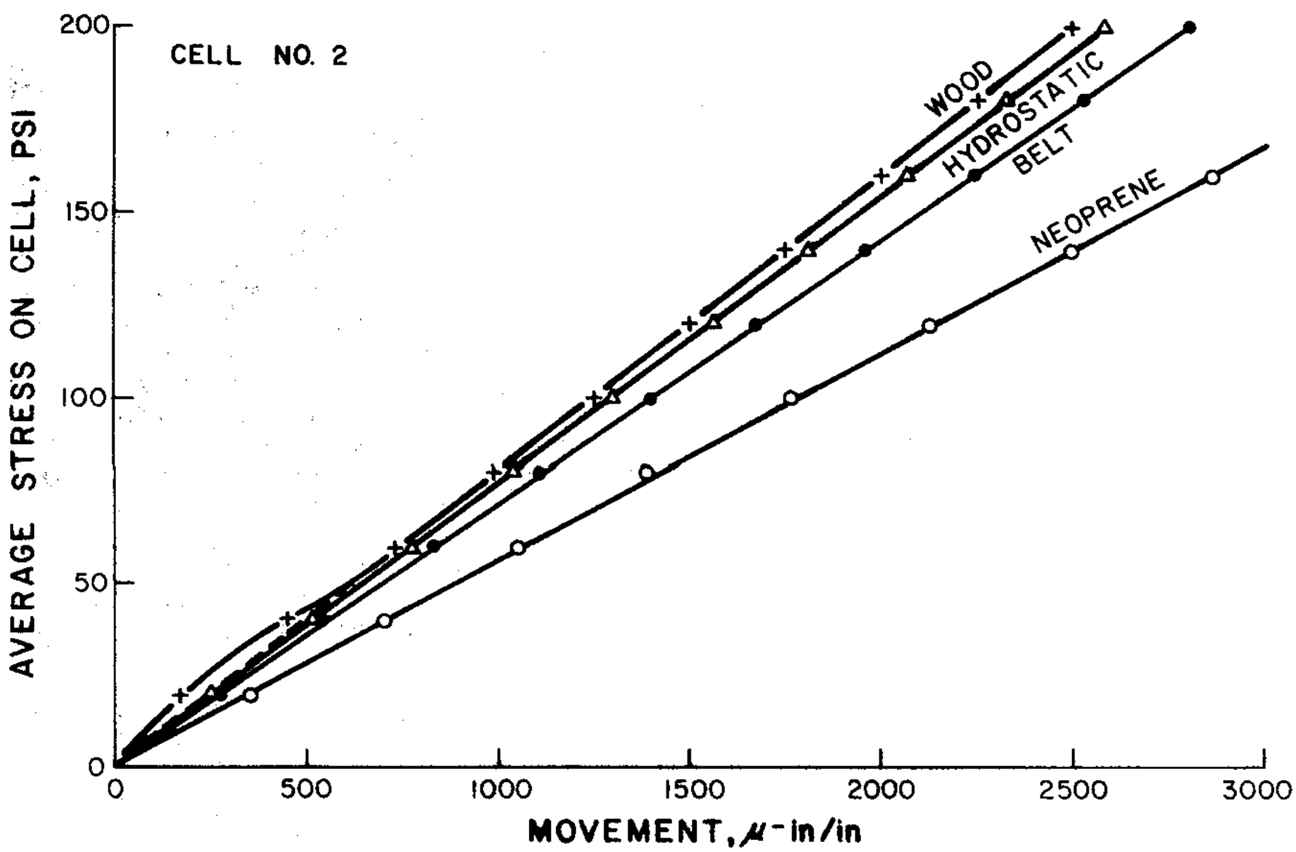


Fig. 9

EFFECT OF VARIOUS BACKING MATERIALS ON SOIL PRESSURE CELL RESPONSES.
(CALIBRATIONS CONDUCTED EARLY IN STUDY)

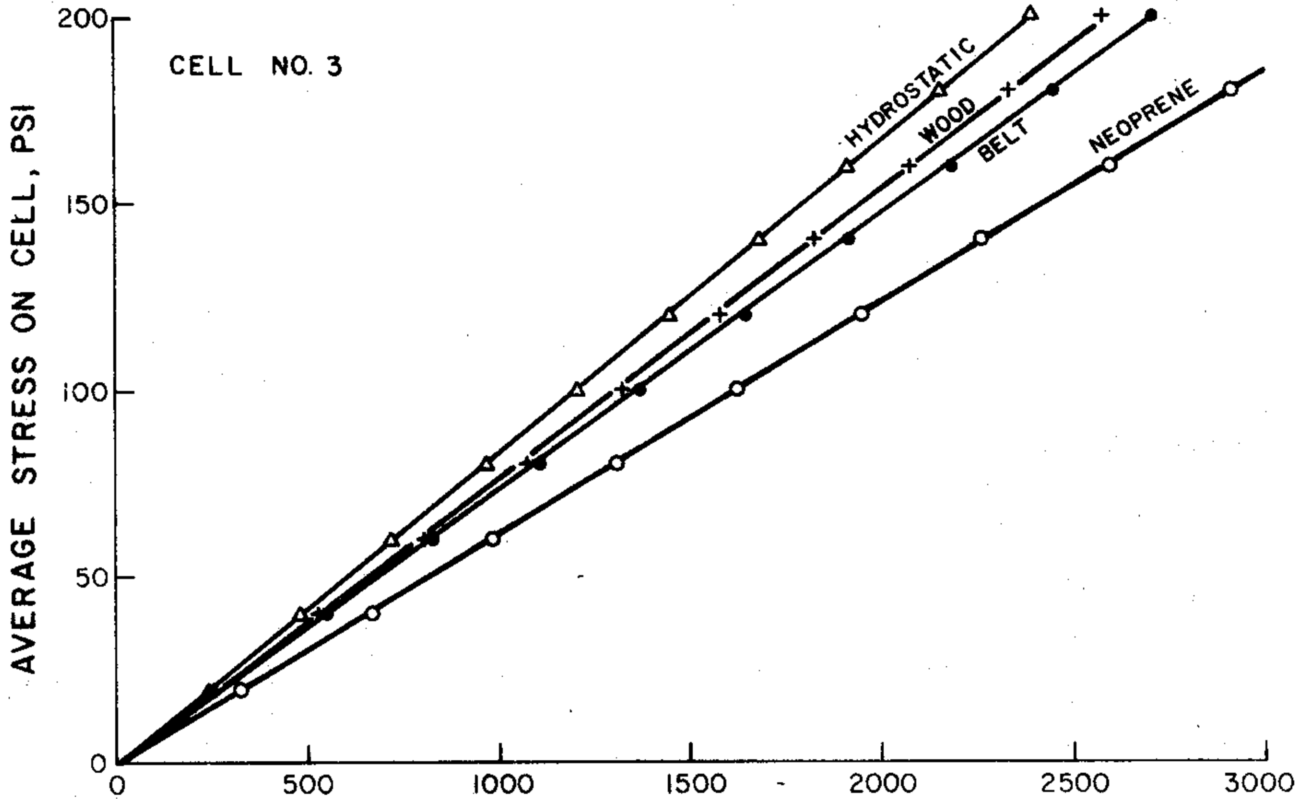


Fig. 10

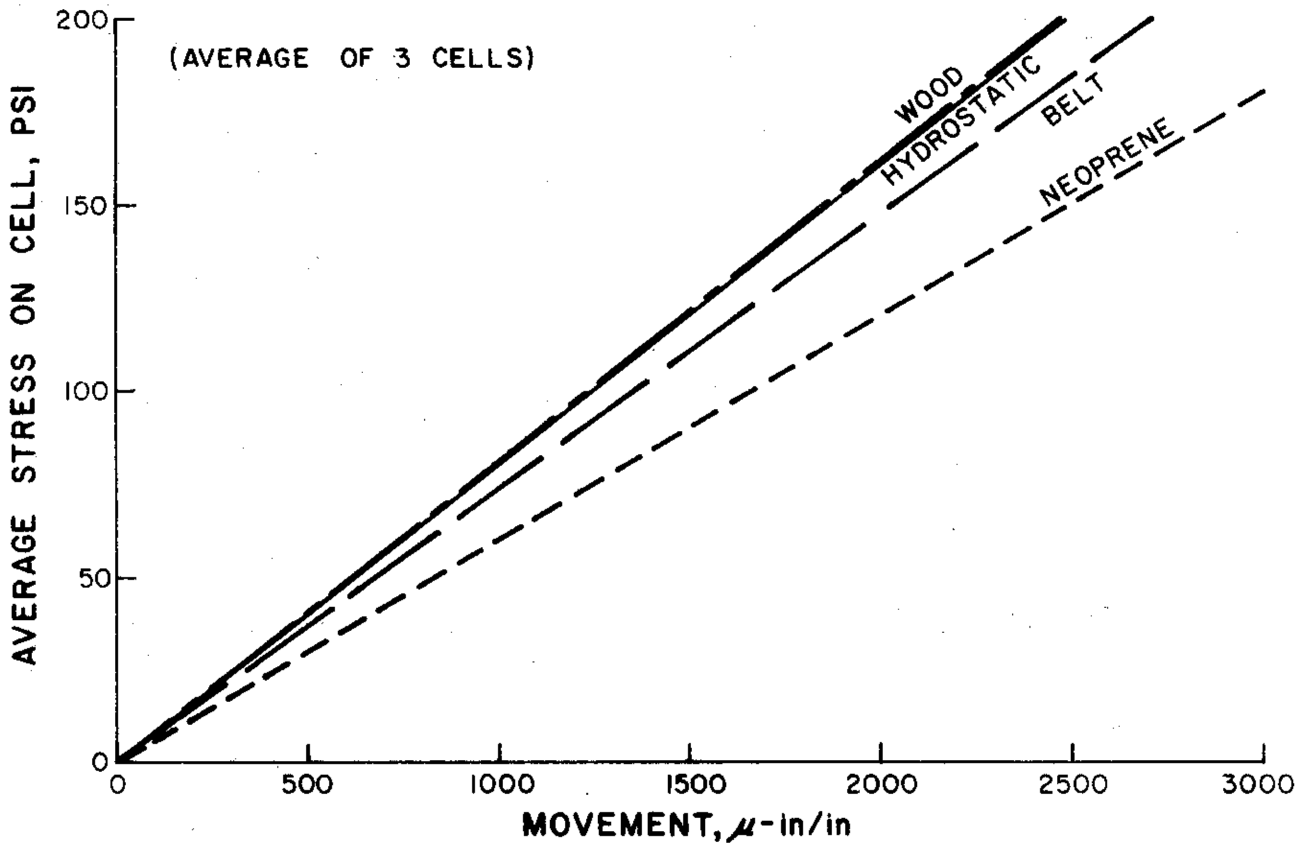


Fig. 11

EFFECT OF VARIOUS BACKING MATERIALS ON SOIL PRESSURE CELL RESPONSES.
(CALIBRATIONS CONDUCTED EARLY IN STUDY)

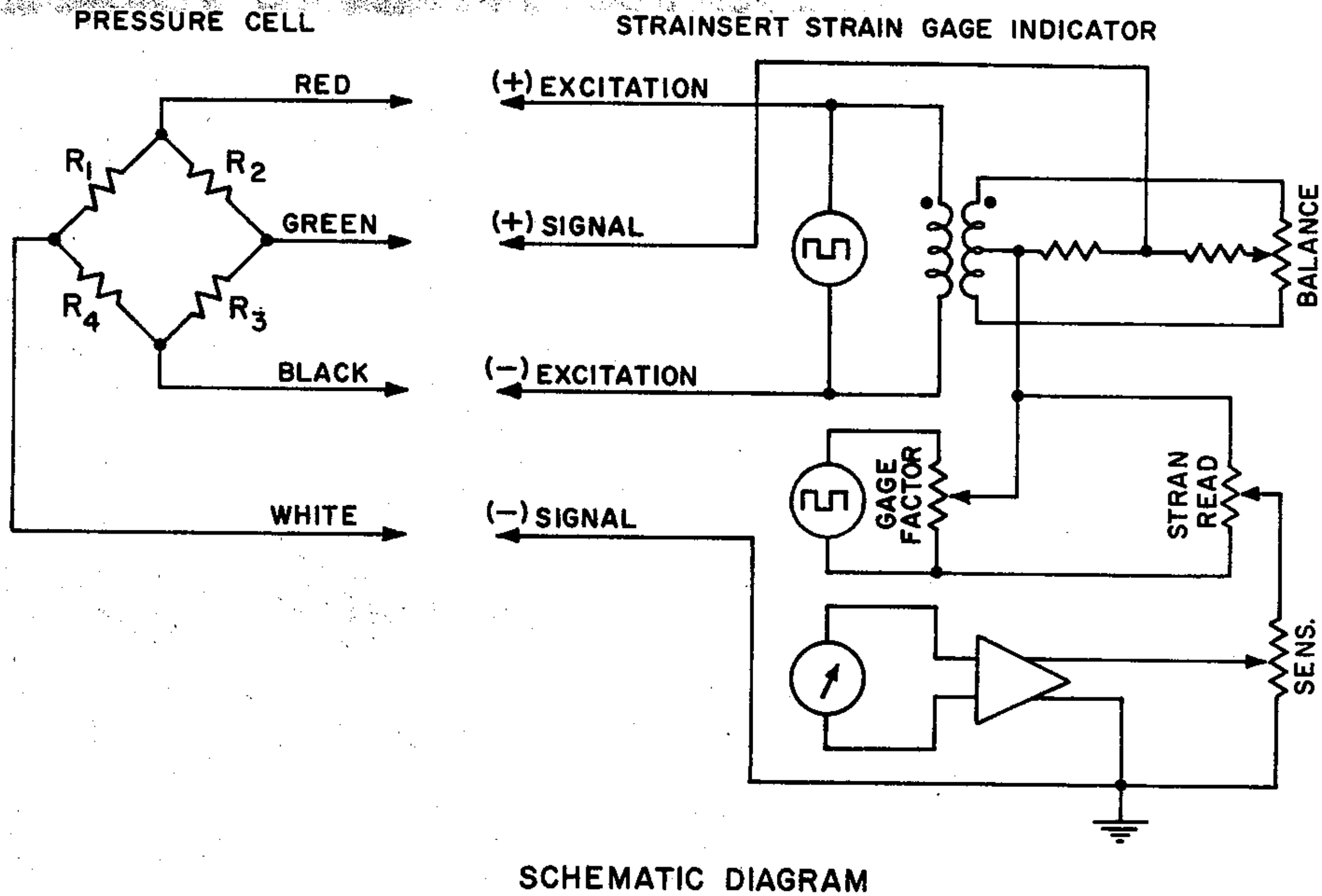


Fig. 12 - PRESSURE CELL BRIDGE AND READOUT DEVICE

standard 8-ply, outdoor type. The preformed fabric is a combination of interwoven cotton duck cloth and rubber, while the neoprene is a homogeneous sheet. Hardness of the fabric and neoprene were Shore A 90 and 60 Durometer, respectively, tested in accordance with ASTM Test D-676. The materials were each 1/2 in. in thickness and cut to 10-in. diameters to just cover the soil pressure cell.

The following is an outline of the calibration procedure:

a. The pressure cells were sandwiched between one of the three types of backing materials and placed in the loading frame utilizing 1-in. thick, 10-in. diameter steel end plates to distribute applied loads. All backing materials jack, plates, and load cell were positioned concentric with the cell.

b. The strain readout meters were connected to the load and pressure cells.

c. The pressure cells were flexed by loading to maximum rated pressure at least two times, then rebounded to zero load.

d. After re-zeroing the strain meters, loads were increased in 1600-lb increments up to 16,000 lb, and pressure cell output recorded at each increment. The procedure was repeated as the cells were re-bounded. (A 1600-lb change in load divided by the surface area of the cell, 80 sq. in., was assumed to produce a 20 psi change in cell fluid pressure.)

e. The calibration procedure was repeated at least two times for each cell and backing material.

f. The average index value from the readout instrument was plotted versus the calculated stress, Figs. 8, 9 and 10. The average values of the three cells are plotted in Fig. 11.

The calibration with neoprene backing in all cases resulted in the highest strain/load response, and wood, in two of the three cells, the lowest.

The rigid frame method of calibration, utilizing all three types of backing material, was performed at two different times during the study; early in the

testing program and at the end. The curves shown on Figs. 8, 9 and 10 are for the three cells used in this study and are representative of calibrations conducted at the end of the study. The first set of calibration curves (see Fig. 13 for a typical curve) were nonlinear at stress levels below 60 to 80 psi. This was assumed at the time to be a characteristic of this calibration method, since identical trends were noticed for each cell. However, the second set of calibrations obtained at the end of the program were nearly linear over the entire stress range, 0-200 psi. Also noticed was a wider spread, or separation, between calibration curves in the early testing as compared to the second set. These discrepancies may be attributed to unnoticed variations in procedure, or factors such as backing material not covering the plate, or an uncentered load cell.
It is concluded that the nonlinearity, and greater spread between the calibrations with the different backing materials, as exhibited by the initial rigid frame testing, can be overcome or reduced by careful procedure. However, it is also evident that this method of calibration is extremely sensitive to the particular conditions of testing.

3. Evaluation

At this point it was judged that further confirming evidence was not necessary to justify the use of the hydrostatic method as a standardized calibration procedure. It was also concluded that it was not essential for hydrostatic cell responses to closely agree with those obtained in soil. Since the hydrostatic method of calibration is extremely repeatable, the variation in cell response would be constant and could be adjusted or accounted for by application of suitable correction factors. Additionally, the hydrostatic method gives linear calibrations and is independent of testing procedure and operator technique. In consideration of this, all subsequent figures and tables, except one, are based on the hydrostatic calibration.

E. COMPACTION AND TESTING OF MATERIALS

1. Granular Soil

a. Compaction

The medium coarse sand and the pea gravel were the first materials selected for studying the

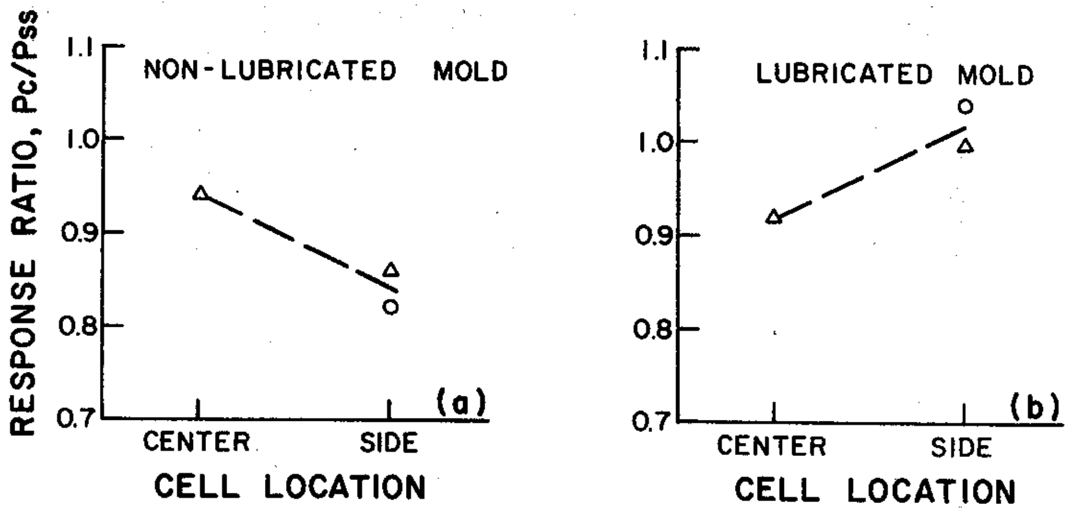


Fig. 21 a & b – Comparison of vertical stress response ratios with cell location.

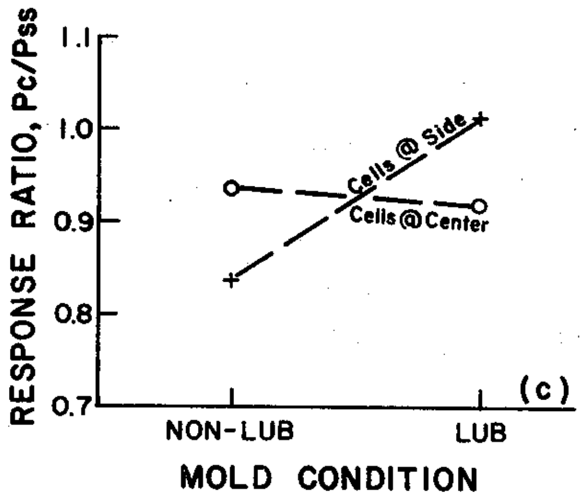


Fig. 21c – Comparison of average vertical stress response ratios with mold condition for different cell locations.

Fig. 21 – TEST RESULTS FOR CELLS IMBEDDED IN SAND WITH 8 INCHES OF SOIL COVER. (LUBRICATED & NON-LUBRICATED MOLD)

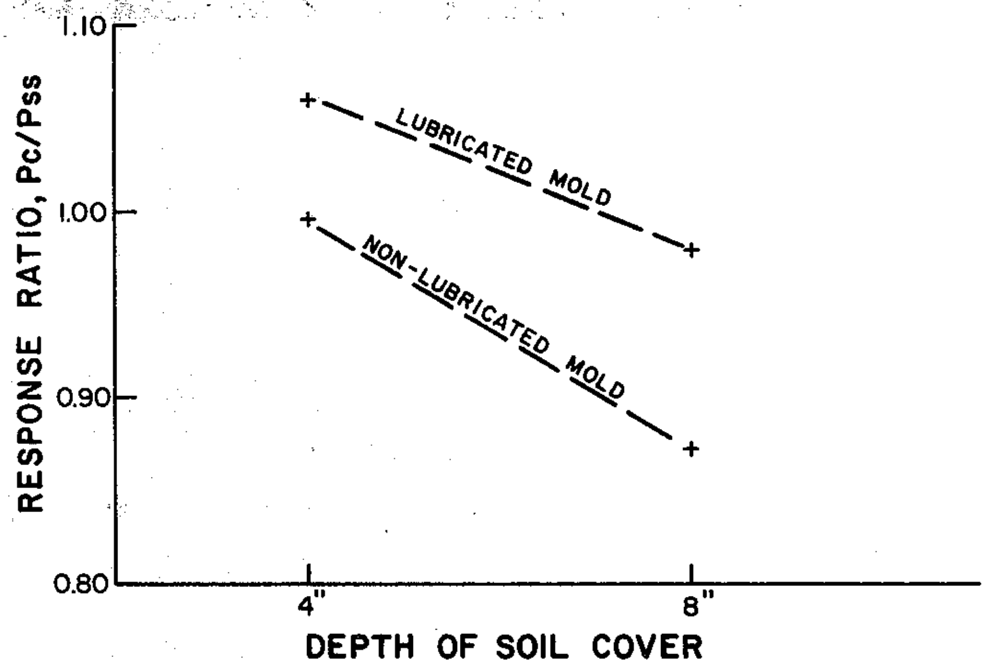


Fig. 22 - COMPARISON OF VERTICAL STRESS RESPONSE RATIOS & SOIL COVER DEPTH FOR SAND AT INDICATED MOLD CONDITION. (RESULTS ARE AN AVERAGE OF ALL TESTS CONDUCTED AT THE NOTED DEPTH).

Tests conducted in pea gravel again indicated a stress gradient from the side of the mold to the center, even with the lubricated mold (Fig. 23a). Average response ratios were about unity. Lateral stresses were also measured (Fig. 23b). The behavior of cells embedded at the 4-in. depth in both granular materials tested is compared in Fig. 24. The higher response shown by the sand could be due to the lower relative density and modulus than that exhibited by the pea gravel.

2. Cohesive Material

a. Compaction

A California compaction test producing 33,000 ft-lb per cu ft of compactive effort and a standard AASHO compaction test producing 12,375 ft-lb per cu ft of compactive effort were performed to determine the range of moisture contents to be used for this test (see Fig. 25). Based on these tests, water contents of 8.0, 15.7, 17.7, and 18.5 percent were arbitrarily chosen to represent moistures ranging from very dry to wet of some optimum condition. The material was compacted into lubricated molds in 3- to 4-in. lifts by hand tamping with a 38 lb, 4-in. diameter hammer. Each lift received 25 blows with the hammer free-falling a distance of approximately one foot. Total applied compactive effort was approximately 1,500 ft-lb per cu ft. A collar was used on the last lift to permit compaction without spillover (Fig. 26). The initial densities, as computed, were quite a bit lower than anticipated. Applying a pre-load of 200 psi, however, densified the soil considerably. The soil densities before and after application of chamber pressure are plotted against moisture content on Fig. 25. It is noted that the "after test" density-moisture curve for the cohesive soil compacted in the chamber was between that of the AASHO and California compaction test curves.

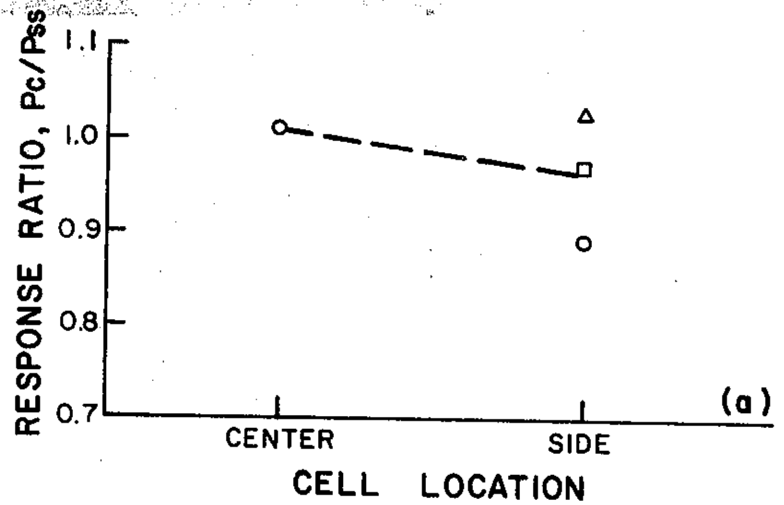


Fig. 23a – Comparison of vertical stress response ratios with cell location.

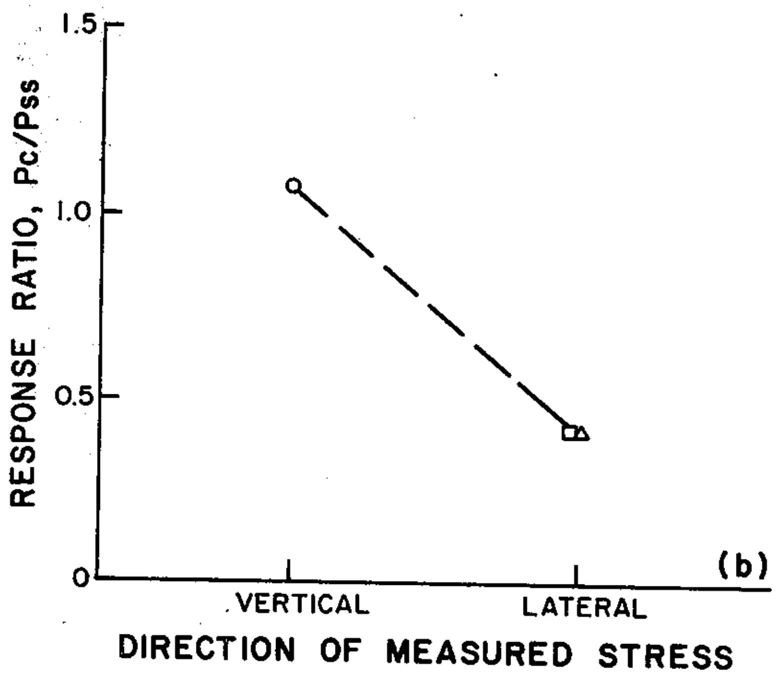


Fig. 23b – Comparison of vertical & lateral stress response ratios.

Fig. 23–TEST RESULTS FOR CELLS EMBEDDED IN PEA GRAVEL UNDER 4 INCHES OF SOIL COVER (LUBRICATED MOLD ONLY).

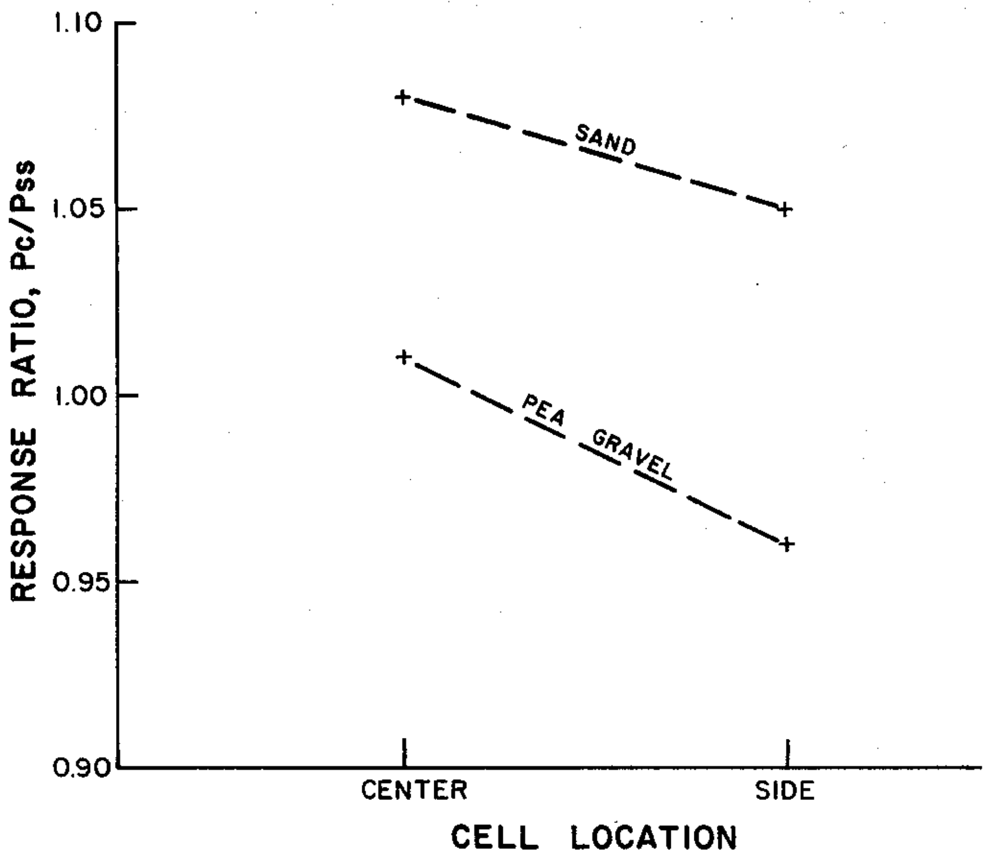


Fig. 24 - COMPARISON OF AVERAGED VERTICAL STRESS RESPONSE RATIOS FOR GRANULAR MATERIALS. (TEST RESULTS FOR LUBRICATED MOLD AND 4 INCH EMBEDMENT DEPTH ONLY.)

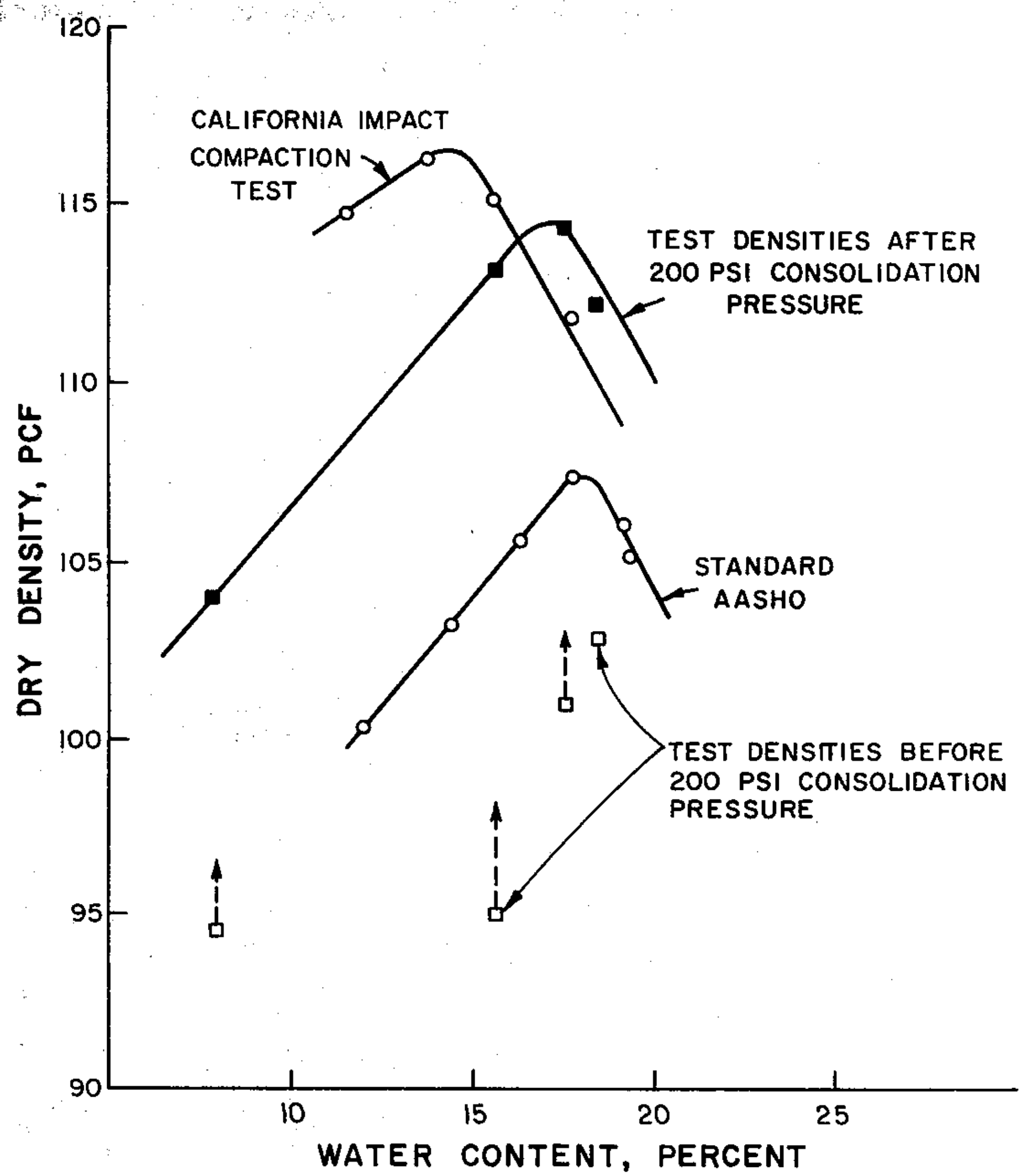


Fig. 25 - COMPACTION CHARACTERISTICS OF LEAN CLAY

Figure 26 - Compaction of the Lean Clay

b. Testing

At each of the moisture contents two cell arrangements were used as shown on Fig. 16a and b. A typical set of data curves is shown on Fig. 27. Since the cell response was not quite linear, for convenience of presentation the response ratio was computed at 100 psi and 200 psi. This information is presented in Table 2. Pressure Cell No. 3 was found to be malfunctioning during Test No. 18 and no data was presented. However, the lateral stress measurements were valid and are presented.

c. Analysis

The average response ratios for the pressure cells placed horizontally varied considerably with moisture content (Figs. 28a and b). Again the effects of mold side friction were evident as shown by the lower response ratios for cells located near the side (Fig. 28c).

The effect of water content on lateral pressure responses was also monitored (Fig. 29). For this cell orientation, response increased with an increase in water content and is attributed to increases in pore pressures.

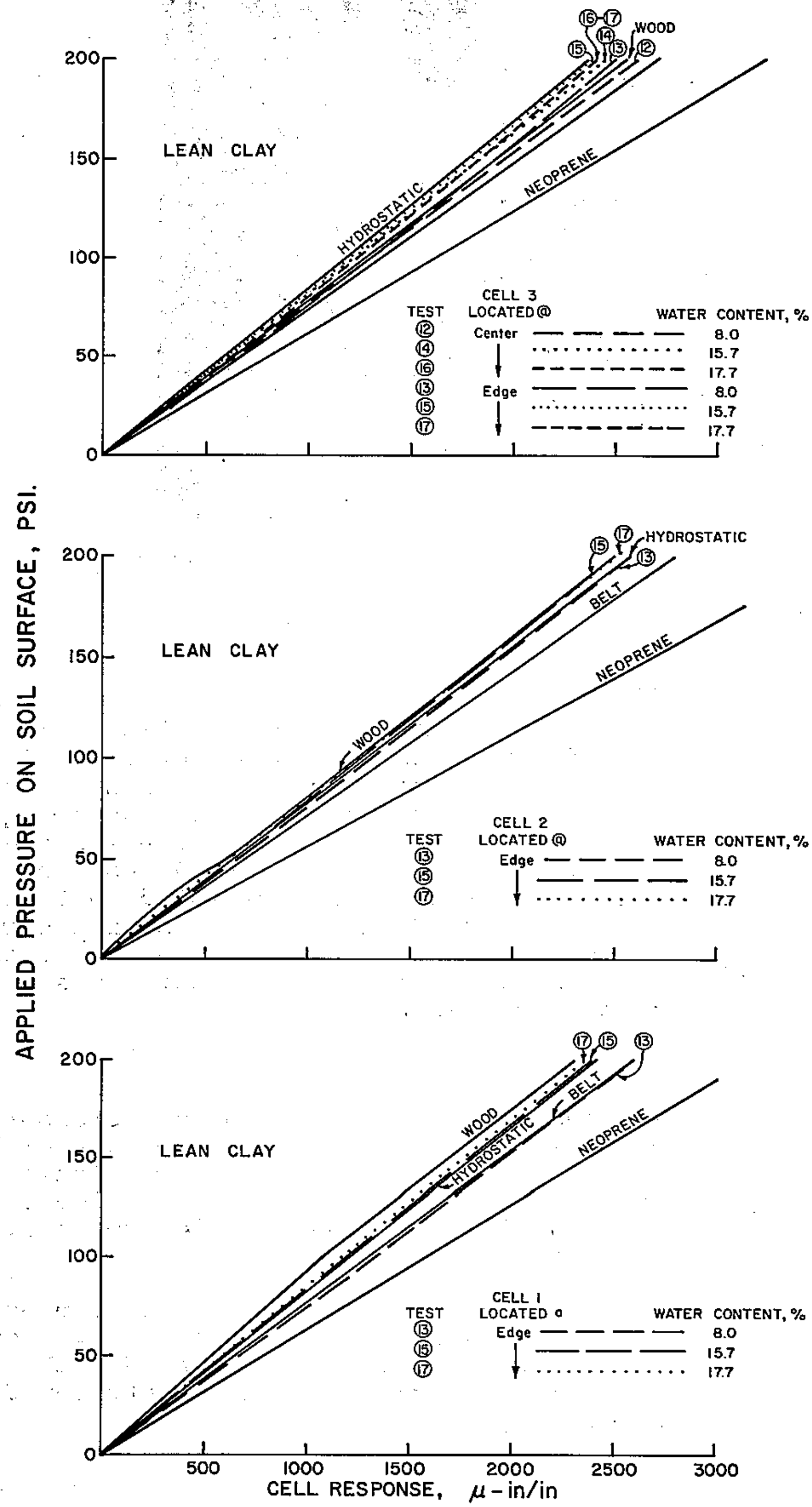


Fig.27 - VARIATION OF CELL RESPONSES DUE TO VARIOUS CALIBRATION METHODS. (CELLS EMBEDDED HORIZONTALLY @ 4" DEPTH. LUBRICATED MOLD).

TABLE 2

Data Summary for Tests Conducted in Lean Clay

Test No.	PSI	Response Ratio - P_c/P_{ss} Cell 1	Cell 2	Cell 3	Cell Placement Depth (Inches)	Location (S = Side) (C = Center)	Lubricated Mold	Water Content Percent
12	100	0.366*	0.341*	1.168	4	C	x	8.0
	200	0.331*	0.303*	1.105				
13	100	1.117	1.023	1.092	4	S	x	8.0
	200	1.074	0.996	1.046				
14	100	0.529*	0.550*	1.059	4	C	x	15.7
	200	0.479*	0.489*	1.017				
15	100	0.992	1.000	1.033	4	S	x	15.7
	200	0.992	0.969	1.004				
16	100	0.430*	0.535*	1.092	4	C	x	17.7
	200	0.434*	0.535*	1.047				
17	100	0.983	0.997	1.051	4	S	x	17.7
	200	0.984	0.969	1.017				
18	100	0.604*	0.627*	NG	4	C	x	18.5
	200	0.660*	0.679*					
Symbol		⊙	△	⊡				

*Lateral stress measurements

Note: P_c = Pressure of cell
P_{ss} = Pressure on soil surface

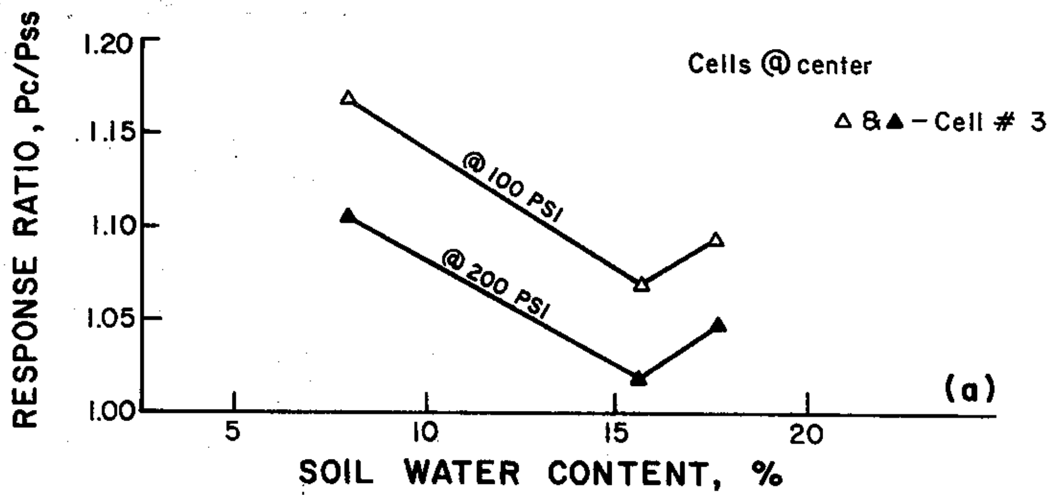


Fig. 28 a – Comparison of vertical stress response ratios with soil water content. Ratio computed for 100 and 200 psi.

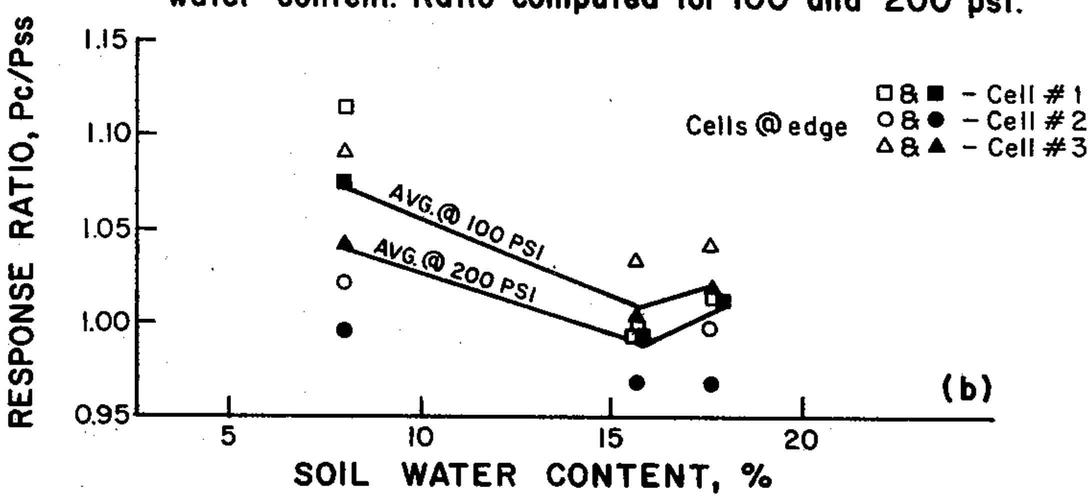


Fig. 28 b – Comparison of vertical stress response ratios with soil water content. Ratios computed for 100 and 200 psi.

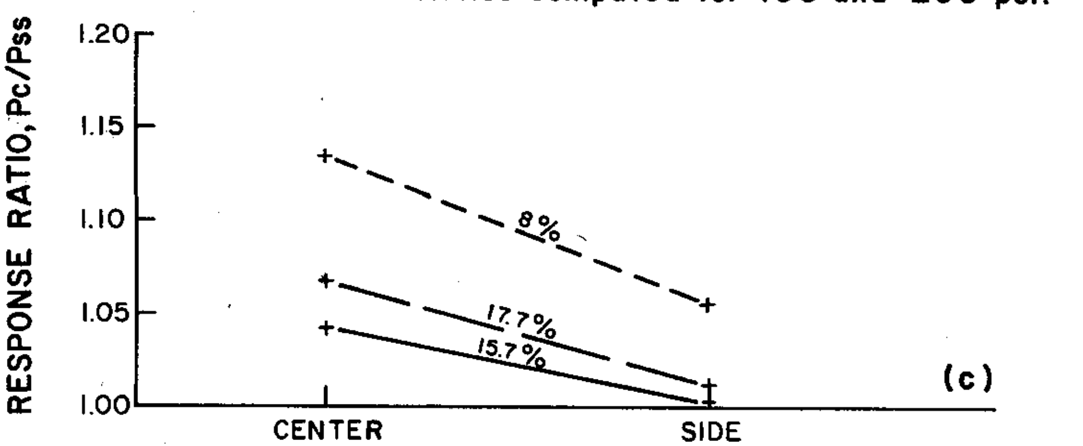


Fig. 28 c – Comparison of vertical stress response ratios with cell location for different soil water contents. Response ratios are an average of the 100 and 200 psi ratios.

Fig. 28 – TEST RESULTS FOR CELLS EMBEDDED IN LEAN CLAY UNDER 4 INCHES OF SOIL COVER (LUBRICATED MOLD)

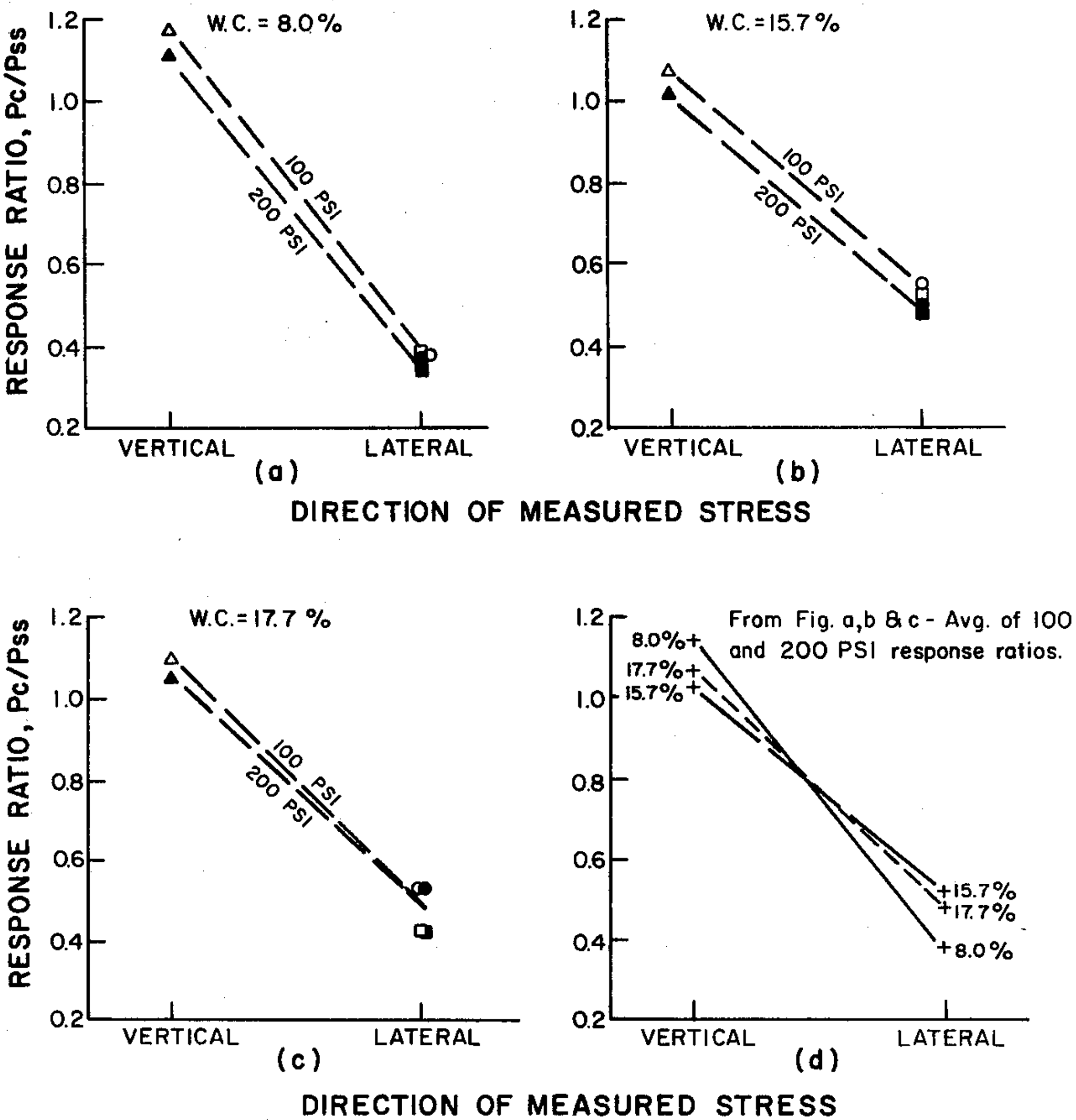


Fig. 29 - COMPARISON OF VERTICAL AND LATERAL STRESS RESPONSE RATIOS FOR TESTS CONDUCTED IN LEAN CLAY AT INDICATED WATER CONTENTS. (LUBRICATED MOLD)

F. ANALYSIS OF THE VARIOUS BEDDING MATERIALS STUDIED

A comparison of the response ratios of the various materials tested is shown in Figs. 30 and 31. Of all of these materials, only the pea gravel exhibited response ratios near unity. These test results seem to indicate that the response of the pressure cells is related to the density and the modulus of the bedding material. The response of pressure cells bedded within cohesive material also seemed to be affected by the water content of that material, whereas this should not be the case for the free-draining pea gravel and sand. Response to lateral pressures also seems to be a function of water content for cells located within the cohesive materials whereas this would not be the case for the granular materials.

In conclusion, there appears little justication for utilizing the cohesive material as bedding material for earth pressure cells unless it is a continuum of the embankment. In addition to its changing characteristics due to variations in moisture, densities are not as easily reproduced as those with sand or pea gravel. The granular materials lend themselves to easy compactibility with small density variations in addition to being free draining and non-plastic. This resulted in predictable pressure cell under- or over-registration.

Previous investigators (References 2, 3 and 5) when testing soil pressure cells in various bedding materials found better correlation of pressure responses when the cells were embedded in wet clay. This may be due to the fact that plastic soils like clays behave similar to a hydraulic or pneumatic confining medium. However, it is concluded that the undesirable features of the clay bedding materials mentioned above outweigh the possible benefits. In addition, the testing reported herein indicate that the discrepancies of response of cells embedded within granular materials is not intolerable and can be readily corrected.

Considerable field testing, or additional laboratory testing on a much larger scale, is necessary to fully evaluate the effect of bedding materials on the response of soil pressure cells. The limited size of the pressure vessel used in this laboratory testing precluded anything but rather general conclusions.

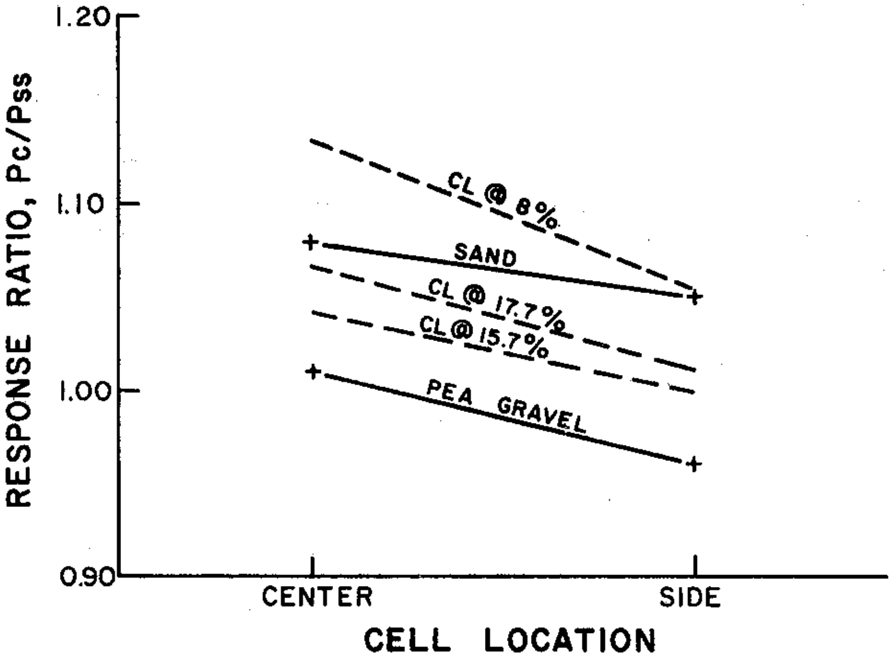


Fig. 30 - COMPARISON OF AVERAGED VERTICAL STRESS RESPONSE RATIOS WITH CELL LOCATION FOR THE 3 BEDDING MATERIALS. (TEST RESULTS FOR CELL EMBEDMENT DEPTH OF 4 INCHES: LUBRICATED MOLD ONLY)

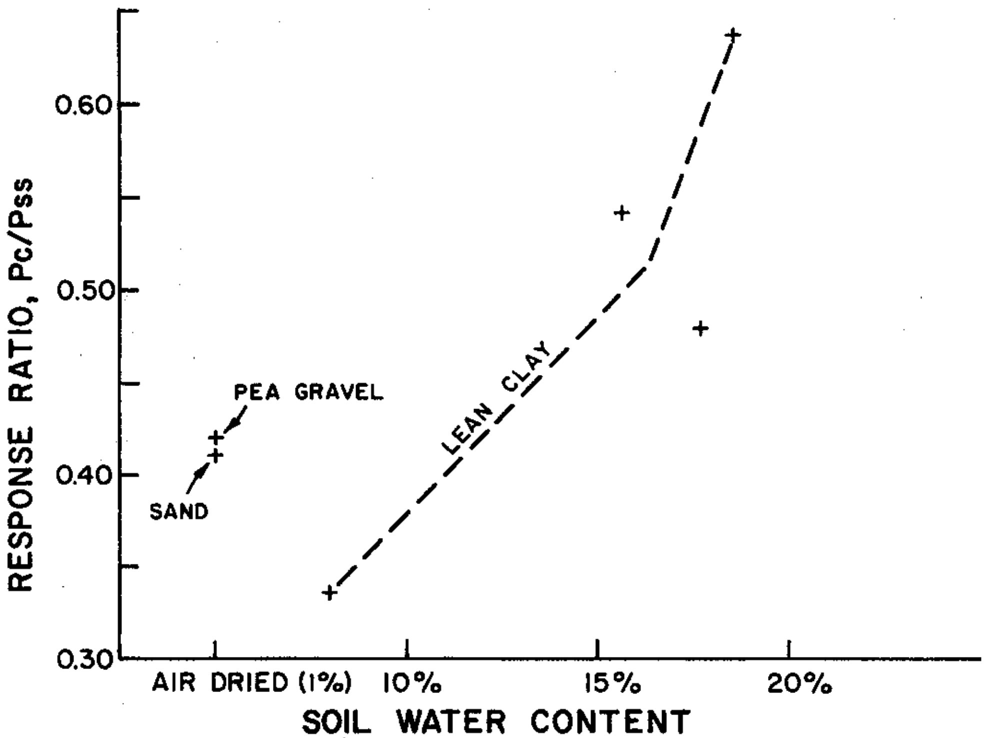


Fig. 31 - COMPARISON OF LATERAL STRESS RESPONSE RATIOS WITH WATER CONTENT FOR THE 3 BEDDING MATERIALS. (LUBRICATED MOLD ONLY)

Since a pressure containment vessel of anything but enormous size would introduce too many test parameters, other work in this field by this agency will be conducted through full scale field testing. The results gleaned from the herein contained laboratory testing will provide guidelines for future field testing.

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